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UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

The Meeting on Energy Conservation
in Small and Medium Industries

Kuala Lumpur, Malaysia, 1-2 December 1983

REPORT*

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1.0 INTRODUCTION

1. The Meeting on Energy Conservation in Small and Medium Industries was convened in Kuala Lumpur, Malaysia on 1st - 2nd December, 1983. The Meeting was officially opened by Mr. Nik Ahmad bin Haji Nik Hassan, Secretary General of The Ministry of Energy, Telecommunication and Posts.

The Meeting was attended by delegates as listed in Annex I.

2.0 ELECTION OF CHAIRMAN

Mr. Syed Mohd. Adlan of the Ministry of Energy, Telecommunication and Posts, Malaysia was elected Chairman of the meeting.

3.0 PRESENTATION OF THE REPORT ON THE SURVEY ON THE ASEAN ENERGY-CONSERVATION PROJECT IN MALAYSIA

The Chairman invited the Project Team to present the findings of the Survey on Energy Conservation in Selected Small and Medium Industries in Malaysia.

The presentation was divided into 3 parts in which the introduction and general aspect of the report was presented by Mr. Masataka Eguichi. Mr. Ryoki Takahashi presented the thermal section while Mr. Toshio Sugimoto spoke on the electrical section of the report.

The Meeting took note of the various findings by the Project Team.

4.0 DISCUSSION ON ENERGY CONSERVATION MEASURES BY THE FACTORIES

The factory representatives then presented their comments as follows:

MARCO SHOES SDN. BHD.,

The representative from Marco Shoes Sdn. Bhd., reported that following the audit by the Project Team, the Factory Energy Conservation Committee had decided to await the final recommendations of the Report from the Project Team before investing funds into energy

conservation measures. In other areas where conservations measures involved house-keeping activities in the factory, the management had initiated action to resolve the problem areas.

The representative mentioned that he had requested for information on more sensitive thermocouple for the autoclave which could be recommend by the Project Team, as the present thermocouples have been found to be not sufficiently sensitive.

In response to the Project Team's recommendation to switch thermocouples between the 2 autoclaves in the factory, the representative informed that this was not possible as the two thermocouples were of different sizes. Regarding the insulation for feed water tank and the drain recovery pipe, he said that insulations on these will be added in June, 1984 when the factory closed down for maintanence.

USMETA SDN. BHD.

The representative from Usmeta Sdn. Bhd., asked the Project Team if there are ways to reduce their energy bills which now amounted to $6,000 - $12,000 per month to retread 3,000 tyres.

The Project Team commented that the factory's steam traps could be faulty as the temperature of water in heat recovery system was 100°C instead of the normal 70 - 80°C. Further, the boiler produced 10 times more steam than is required by the factory. By repairing/replacing the faulty steam traps, the Project Team felt that this factory could save 20 - 30% of their fuel costs.

The Malaysian Counterpart further commented on the reliability of the steam traps and suggested that Usmeta Sdn. Bhd., could seek assistance from the Malaysian Counterparts.

The factory representative replied that even in spite of having replaced all the steam traps and having insulated all their pipes, there had been no significant savings in their energy bill. The

Japanese Project Team suggested that the Factory could switch from present open system of heat recovery to the closed system, that is by using a pressure tank.

The Malaysian Counterpart added that another alternative to cut fuel costs would be to change to a smaller boiler. In regard to this, a delegate said that this would not be necessary as steam output could be adjusted by controlling the rate of boiler firing.

SOUTH EAST ASIA FIREBRICKS INDUSTRIES

The representative informed the meeting that during the time of the Project Team visit in April, the factory had requested that the team concentrate its study on the smallest of its 3 kilns. The factory felt that this kiln had not been very efficient in fuel consumption. The factory had also requested that Project Team to study the feasibility of using the waste heat from the stack of this particular kiln as the waste heat from the stacks of the other 2 kilns have been already used for preheating.

This representative also informed the meeting that it did not have any indicating instrument to help them to reduce the oxygen contents of the flue gas. In response, the Project Team said that this could be done by visual means and there was no need for any instruments. With experience, the factory could adjust the oxygen content of the boiler feed air. If the smoke from the chimney is dark, this showed that there was insufficient oxygen for combustion. On the other hand if the smoke is clear, it indicates sufficient oxygen to the boiler for combustion but this could also result in loss of heat from the flue gas.

GENERAL CERAMICS MANUFACTURERS SDN. BHD.

The Factory representative informed that although the internal wall of their tunnel kiln had been lined with aluminium blankets, the factory still spent about $125,000 per month on fuel. This amounted to about 25% of the factory's operating costs. The representative requested the Project Team to suggest proper insulating methods and the costs involved.

The Project Team responded that the factory should consider having insulation on the external walls of the kiln and rockwool was suggested as a suitable material. It was also added that the factory could use waste heat from the flue gas to preheat air entering the combustion chamber.

The factory representative explained that by relining their ball millers, a saving of 20% on electricity consumption had been achieved. The factory representative further requested for advice on the feasibility of installing 2 transformers of 500 KVA capacity in the factory. To this the Malaysian Project Team replied that the electricity load had to be known first before they could make any comments.

MALAYA INDUSTRIAL AND MINING CORPORATION

The representative of Malaysian Industrial and Mining Corporation made some comments which were based on the findings of the Project Team. The Project Team had reported that the voltage level in the factory was too high. However, according to the factory records the voltage very often dropped to as low as 380 volts and was responsible for the motors burning out. Although the motors was found to be undersized for many of the factory's requirements, the factory management considered the cost of a new motors prohibitive. The factory would be setting up its own power station in the process of expansion and hoped to rectify the voltage problem.

Following the recommendation of the Project Team, the factory had switched some of their fluorescent lamps to mercury lamps but found that their electricity costs much higher. Moreover, the large amount of cement dust corroded the mercury lamp and shortened the lifetime.

The representative further added that the factory was considering changing the firing gun in the kiln, as the oxygen level was too low in the kilns. An additional blower has been installed

in the kiln but an accurate picture of the effects on the consumption of fuel oil could only be obtained in one or two years time. The representative also felt that with the plant running continuously and shutting down a costly affair, the factory management would consider brick lining only when it is forced to cease operations following a major breakdown.

He added that it would be difficult to form an Energy-Saving Committee as most of the factory workers are illiterate and training will require considerable time. The door of the kiln is sometimes kept open to prevent over-heating of the clinker.

The Project Team in turn responded that to avoid the motor burning out, it should not be run at full load. The motor could be run at a maximum of 90% of the rated voltage. The mercury lamps were recommended as a safety measure for the workers and not for economic reasons, and the rise in the electricity bill was anticipated.

The Project Team did not recommend installation of an additional blower. However it recommended the control of combustion be improved at the rotary dryer.

The Project Team also recommended that the heat from the cooling chamber be recovered and used to preheat the fuel oil to a temperature above 30°C. The fuel oil could then be heated to 100°C by using the electrical heater. Waste heat recovered by this method could save about $60,000 per annum.

CHEMPAKA NEGERI LAKSHIMI TEXTILE SDN. BHD.

The representative from Chempaka Negeri Lakshimi Textile Sdn. Bhd., informed the Meeting that the factory was now operating at maximum capacity and at 1867 Amps which exceeded the transformer rating of 1666 Amps. In this context the representative inquired whether the Project Team would still recommend the use of one transformer.

The representative sought advice on the recommendation to reduce maximum demand load and utilizing maximum load alarm indicator. Advice was also required on the means to decreasing the air-conditioning load by relocating the heat dissipating equipments such as compressors and capacitors.

The Project Team's responded that two smaller transformers could be used but it was still possible to use one of the existing transformers by adjusting the voltage.

It suggested that an 'indicator system' could be installed together with redistribution of load. With regard to reducing the airconditioning load, the Project Team felt that an absorption type of air-conditioner coud be installed together with a microprocessor so that the maximum level of air-conditioner load can be automatically controlled.

FUSAN FISHING NET MANUFACTURING BHD

The factory representative reported that energy costs amounted to about 10% of total operation costs, out of which 9% was for electricity and the other 1% for fuel oil. This worked out to be about $70,000 on electricity and about $10,000 on fuel oil per month.

Whenever possible the factory had implemented some of the recommendations made by the Project Team. The factory had borrowed an oxygen meter from NEB and undertook the necessary adjustment on the boilers as recommended by the Project Team. However this had not been effective and till of date there had been no significant savings.

The factory inquired of the Project Team as to the reason of using 0.5 as the value of the diversity factor in calculating the power consumed. The Project Team replied that it was assumed that 50% of the heater was off most of the time.

The factory representative also pointed out that the raw material used was polyethylene and not polyester as mentioned in the report. The Project Team during its visit to the factory noted that the water in the boiler and also the boiler blow down water were not as clean as it should be. Following the recommendations to improve this, the factory cleans the boiler once a month on the fire side and one in 3 months on the water side.

The Project Team had noted that steam was being used in both the dyeing and stretching processes and of the two, the stretching process offered very good potential for savings. In this respect, the factory representative sought more information on the steam accumulator as recommended in the report. According to their calculations, the steam accumulator to be incorporated into their present system will have to be very large to provide for the steam requirement of the factory. Both the factory and the Project Team agreed to resolve this outside the meeting proper.

Touching on points raised by the factory representative on the boiler and steam accumulator, the Project Team stated that under normal circumstances, there is a necessity to blow down the boiler because a situation where there is a high concentration of chemicals in the boiler water would cause deteriorotion of the boiler. A simple way to decide when to have a blow down is to check the pH value and the conductivity of the boiler water with the value recommendated by the boiler chemical manufacturer. It was also explained that steam accumulators have been widely used in Felda palm oil refineries and are known as back pressure vessels.

The capacitor used in this factory was also over powered. Change into a more appropiately rated capacity could result in some savings.

The representative concluded that the factory, since implementing some of the recommendations had recorded savings of 20% on its energy bill.

KIMA SDN. BHD.

The factory representative elaborated on the recommendations made by the Project Team and raised some issues which the factory will have to consider before implementing these recommendations.

According to the Project Team, the factory could save about $12,000 per year on electricity costs if 3 of the existing transformers are shut down. However, this would require an investment of about $70,000 for rewiring and to modify the switch rooms and switch boards. The factory was rather reluctant to undertake this considering that the payback period would be 6 years.

Similarly the factory was also reluctant to install fuel oil and water meters to monitor boiler efficiency and to increase the factory lighting to brighter level as these required very big investments. As the cost estimates amounting to about $200,000 may be required to implement all the recommendations given by the Project Team, the factory was now compiling all the proposals into a report to be brought to the attention of the Factory Management. In the mean time certain sections of the factory was now being studied by a Japanese Government Aid team for possible modifications to diversify the products.

GOH BAN HUAT POTTERY WORKS SDN. BHD.

After expressing his thanks to the relevant parties, the factory representative informed the meeting that his factory had carried out some of the recommendations made by the Project Team while some recommendations will be implemented after studying the official report.

The factory have tried reducing the oxygen content of the flue gas from 10% to 5%. This however was found to have an effect on the quality of the finished products. Under this situation, the Project Team agreed that it will not be advisable to reduce the oxygen content of

the combustion air. The factory was also redesigning it's dryer as it was found to be not satisfactory.

In the meantime the factory has reduced the heating cycle from 36 hours to 32 hours.

5.0 CONSIDERATION OF PROPOSAL ON FRAMEWORK OF MALAYSIAN ENERGY CONSERVATION CENTRE

Mr. Kenji Kondo, on behalf of the Ministry of International Trade and Industry (MITI) and the Japanese Government, presented a paper on 'Energy Conservation Project in Malaysia'. He stressed that the Malaysian enterprises should make full use of the findings of the field survey.

Mr. Eguichi presented a paper on 'A study on establishment of Energy Conservation Centre of Malaysia'. He further elaborated on the typical Japanese Energy Conservation set up of factory level which normally functioned as follows:-

The Head Office decides on policy issues, including company target e.g. energy consumption must be reduced by 10%, which is relayed to a Committee. The Committee in turn will inform the factory manager. Within a factory, number of small groups of 3 - 5 persons exist which are headed by the foreman. Then factory manager will direct the small groups to think of ways and means to achieve the target of 10% reduction in energy consumption. Small groups then report back to the factory manager who will then report to the Committee for decision.

6.0 DISCUSSION ON NATIONAL ENERGY CONSERVATION PROGRAMME THROUGH APPRIPRIATE MECHANISM AND INFRASTRUCTURE

The chairman invited the factory representatives to comment on the extent of which they have benefitted from the project and how the implementation of the project can be improved and whether such energy auditing be extended to other factories.

The factories generally were of the opinion that the project had been an eye opener particularly to the top management. Up to now most of the factories had given little if at all any emphasis to energy conservation, however through the factory-survey and its findings through the project team had shown them the importance of energy conservation and potential for reduction in their energy bills. One factory in particular remarked that if the recommendations were implemented in their factory, their energy bill would be reduced by 30% without much investment.

The factories hoped that the National Electricity Board counterparts would be willing to continue rendering their service in energy auditing and in advising the factories on the methods and techniques of implementing the recommendations in the report.

Two of the factories suggested the formation of a committee with its members consisting of the nine factory representatives and the Natrional Electricity Board team members. This committee would look into the techniques required, solutions to their individual problems and exchange of experiences which could subsequently be disseminated for the benefit of the other factories.

One factory inquired whether the National Electricity Board project team could offer training programmes to factory engineers. The leader of the project team responded that it would be better if the factories approached their own organisations, for e.g. rubber, textile associations.

The UNIDO representative remarked that the objectives of the project was not to limit the benefits of energy management to only 9 factories but to ensure that the technology transfer from Japan to Malaysia would benefit all small and medium factories in Malaysia. It is hoped that the National Electricity Board will carry out such a field survey in other small and medium scale industries in the country.

It was also pointed out that the Field Survey Report after modification and adjustment together with the Guide Book will be disseminated to all the participants.

The Chairman remarked that the necessity of an energy conservation centre in Malaysia requires further study by the Malaysian authorities.

The leader of Malaysian Counterparts replied that while it is true that the technical knowhow and energy conservation equipment have been imparted to the local counterparts, the team would only conduct energy audits upon request from the factories. He added that the Ministry of Energy Telecommunications and Posts might want to liase with the Federation of Malaysia Manufacturers to obtain names of factories intereested in having an energy diagnosis carried out in their factories. The NEB project team will then consider extending the services.

The Chairman thanked all the participants for their useful contribution to the meeting and wished them success in their energy conservation efforts in future.

ANNEX I

LIST OF PARTICIPANTS

		Name	Designation
UNIDO	1.	Dr. H.W. Pack	Senior Officer, P.O. Box 400, Vienna
Japanese Government Officials	2.	Mr. Hidetoshi Hayakawa	Representative of the Japanese Government, MITI 1-3-1 Kasumigaseki Chiyoda-ku Tokyo
	3.	Mr. Kenji Kondo	Representative of the Japanese Government, MITI 1-3-1 Kasumigaseki Chiyodaku, Tokyo
Malaysian Government Officials	4.	Mr. Mokhtar bin Yaacob	Deputy Secretary General Ministry of Energy, Telecommunications and Posts, Malaysia
	5.	Mr. Syed Mohd. Adlan	Head of Energy Unit Ministry of Energy, Telecommunications and Posts, Malaysia
	6.	Mr. Mohamed Annuar Shamsudin	Principal Assistant Secretary (Energy), Ministry of Energy, Telecommunications and Posts, Malaysia
Japanese Survey Team	7.	Mr. Masataka Eguchi	Team leader Expert (energy management) 2-39-3 Nishihinbashi Minato-ku, Tokyo
	8.	Mr. Ryoji Takahashi	Expert, (thermal) Energy Conservation of Japan, Shinbashi, Tokyo

		Name	Designation
	9.	Mr. T. Sugimoto	Expert, (electrical) Energy Conservation of Japan, Shinbashi, Tokyo
Malaysian Counterparts	10.	Dr. Ariff Araff	Senior Engineer, National Electricity Board, Malaysia
	11.	Dr. Ong Peng Su	Engineer, National Electricity Board, Malaysia
	12.	Mr. Ahmad Faizul Shamsuddin	Research Engineer, National Electricity Board, Malaysia
	13.	Mr. Alizan Abdul Manan	Planning Engineer, Ministry of Energy, Telecommunications and Posts
Factory Representatives	14.	Mr. A. Ganesan	Factory Manager, Marco Shoes Sdn. Bhd., Pandamaran, Pelabuhan Kelang
	15.	Mr. Choo Kwok Chiang	Production Manager, Fusan Fishing Net Manufacturing Bhd., Jalan North Port, Pelabuhan Kelang
	16.	Mr. Hew Foot Lin	Engineering Manager, KIMA Sdn. Bhd., P.O. Box 3, Kajang
	17.	Mr. Ismail Mohd. Yassin	Production Executive, USMETA Sdn. Bhd., No.2 Lorong Enggang Empat, Kg. Datuk Keramat Tembakau, Kuala Lumpur
	18.	Mr. M. Rajendran	Assistant Maintenance Engineer, Cempaka Negeri Laksmi Textile, Senawang Industrial Estate, Seremban, Negeri Sembilan

		Name	Designation
	19.	Mr. Tan Boo Chin	Technical Engineer, South East Asia Firebricks Industries, Batu 8 3/4, Jalan Ipoh, Kuala Lumpur
	20.	Y.M. Tunku Abdul Muthalib bin Tunku Nong	Production Manager, General Ceramic Manufacture Sdn. Bhd., Lot 6, Jalan Bersatu, Petaling Jaya
	21.	Mr. Chin Lip Kee	Technical Assistant, Malaya Industrial Mining Corp. Sdn. Bhd. Batu Caves, Selangor
	22.	Mr. Vernon Perera	Plant Manager, Goh Ban Huat Pottery Works 238, Jalan Segambut, Kuala Lumpur
Observers	23.	Mr. Abu Bakar Ismail	Head Energy Unit, Research Department PETRONAS, P.O. Box 2444, No. 136, Jalan Pudu, Kuala Lumpur
	24.	Dr. G. Raju	Senior Planning Officer,
	25.	Mr. Heoe Hock Fie	Engineer, Universiti Pertanian Malaysia, Serdang, Selangor
	26.	Mr. Ismail bin Mustapha	Planning Engineer, Ministry of Energy, Telecommunications and Posts, Wisma Damansara, Kuala Lumpur
	27.	Mr. Japri bin Ahmad	HICOM, Assistant Project Manager, Tingkat 6-9, Wisma Yeng Chong, P.O. Box 707, Jalan Puncak, Kuala Lumpur

	Name	Designation
28.	Ms. Margaret Chow	Economist, MIDA, Wisma Damansara, Jalan Semantan, Kuala Lumpur
29.	Mr. Misron bin Yusof	Director, Sultan Ahmad Shah Training Institute, N.E.B. Bangi, Selangor
30.	Dr. Mohamad Awang Lah	Engineering Faculty, University of Malaya, Jalan Pantai Baru, Kuala Lumpur
31.	Dr. Mohamad Jamel Basha	Physics Research Centre, Universiti Sains Malaysia, Minden, Penang
32.	Prof. Madya Muhamad Yahya	Head, Physics Department, Physics and Applied Science Faculty, Universiti Kebangsaan Malaysia, Bangi, Selangor.
33.	Dr. Mustapha Yusoff	Senior Research Officer, SIRIM
34.	Prof. Madya Omar Munir	Deputy Vice-Chancellor, Universiti Teknologi Malaysia Jalan Gurney, Kuala Lumpur

ANNEX II

AGENDA

Thursday, 1st. December

8.30 am - 9.00 am	-	Registration of participants
9.00 am - 9.15 am	-	Participants to be seated
9.15 am	-	Arrival of The Secretary General, Ministry of Energy, Telecommunications and Posts, Malaysia
9.20 am	-	Welcome address by Deputy Secretary General, Ministry of Energy, Telecommunications and Posts, Malaysia
	-	Opening address by The Secretary General, Ministry of Energy, Telecommunications and Posts, Malaysia
9.45 am - 10.15 am	-	Refreshments
10.15 am - 10.20 am	-	Election of Chairman
10.20 am - 12.45 pm	-	Presentation of audit report by experts from Japan and Malaysia
12.45 pm - 2.00 pm	-	Lunch hosted by The Secretary General, Ministry of Energy, Telecommunications and Posts, Malaysia
2.00 pm - 3.15 pm	-	Report and discussion by factory representatives
3.15 pm - 3.30 pm	-	Refreshments
3.30 pm - 5.00 pm	-	Discussion continues

Friday, 2nd. December

9.00 am - 10.00 am	-	Discussion continues
10.00 am - 10.30 am	-	Refreshments
10.30 am - 11.30 am	-	Discussion continues
11.30 am - 12.45 pm	-	Presentation by Japanese experts on "Framework of Malaysian Energy Conservation Centre"
12.45 pm - 2.00 pm	-	Lunch
2.00 pm - 3.15 pm	-	Discussion on "National Energy Conservation Programme Through Appropriate Mechanism and Infrastruture"
3.15 pm - 3.30 pm	-	Refreshments
3.30 pm - 5.00 pm	-	Recommendations and conclusion

ANNEX III

LIST OF DOCUMENTS

1. Report on the survey on the ASEAN Energy-Conservation Project in Malaysia (UNIDO publication No: UNIDO/IS).

2. A study on establishment of Energy-Conservation Center of Malaysia (UNIDO publication No: UNIDO/IS).

3. Guide Book for the Factory Engineers on Energy Conservation Diagonosis (UNIDO publication No: UNIDO/IS).

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A SILICON FOUNDRY TO SERVICE DEVELOPING COUNTRIES' NEEDS: A PRELIMINARY APPROACH

Prepared by the UNIDO secretariat*

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1. Trends in Microelectronics and the Needs of Developing Countries

The semiconductor industry operates at the forefront of current technology. Microelectronics is continuously advancing and perhaps the most obvious trend in it is the rapid increase in complexity of integrated circuits.

The first experimental integrated circuit produced in the 1950s contained only a few components per chip. By 1964, commercially available chips had around ten components; by 1970, that number was close to 1000; by 1976, it had risen to 30,000 and today it is close to 1,000,000. In fact, this growth has been stated in the form of a law: Moore's Law, first expressed in 1974. Based upon the short history of the industry, Moore's Law predicted that the number of components per chip would aproximately double each year. And so it has. Along with the rapidly increasing complexity has come an equally rapid decrease in the cost per function for chips produced in large volumes.

These two trends have combined to make the integrated circuit suitable for a wider and wider range of applications. In the days of small and medium scale integration with fewer than about 1000 devices per chip, IC's were used mainly for fabricating the fundamental building blocks of digital computing systems such as logic gates, flip flops and so on. These types of circuits were usable in a tremendous variety of applications and were demanded in huge volumes. Thus the cost was low. However, as the complexity of chips has increased they have, in general, become more and more specialized and fewer of each are required. Thus with increasing complexity the use of IC's has become more widespread while at the same time the use of a particular type of IC has become more and more limited. Design time has increased with complexity as has the cost of documentation of the design. Therefore, the price paid for developing and producing a complex, specialized chip tends to be increasing.

There have, however, been several technological innovations which have allowed the industry, and thus the user of integrated circuits, to break out of the cycle of greater complexity - smaller range of applications - higher costs.

One is the micro-processor - a complex circuit with a very wide range of applications. The fundamental reason why the micro-processor has been so successful is that its actual function is not defined until after it has been completely manufactured. The function is defined by the software and the software can be tailored to satisfy a wide range of needs.

It is well accepted now that micro-processor technology has immense potentialities for development-catalyzing applications for developing countries in areas such as agriculture, healthcare, education, rural industrialization etc. The best possibilities for exploiting this technology lie in designing and fabricating processor chips for well defined applications in these areas, e.g. soil-testing, blood-sugar analysis, other suitable pathology tests, analysis of fat content of milk in dairy industry,and so on. Similarly, there would seem to be a considerable scope for applying microelectronics to the advancement of literary and community-level publication - especially in areas where the written medium employs scripts widely different from the Latin alphabet.

2. Silicon Foundry Approach for Developing Countries

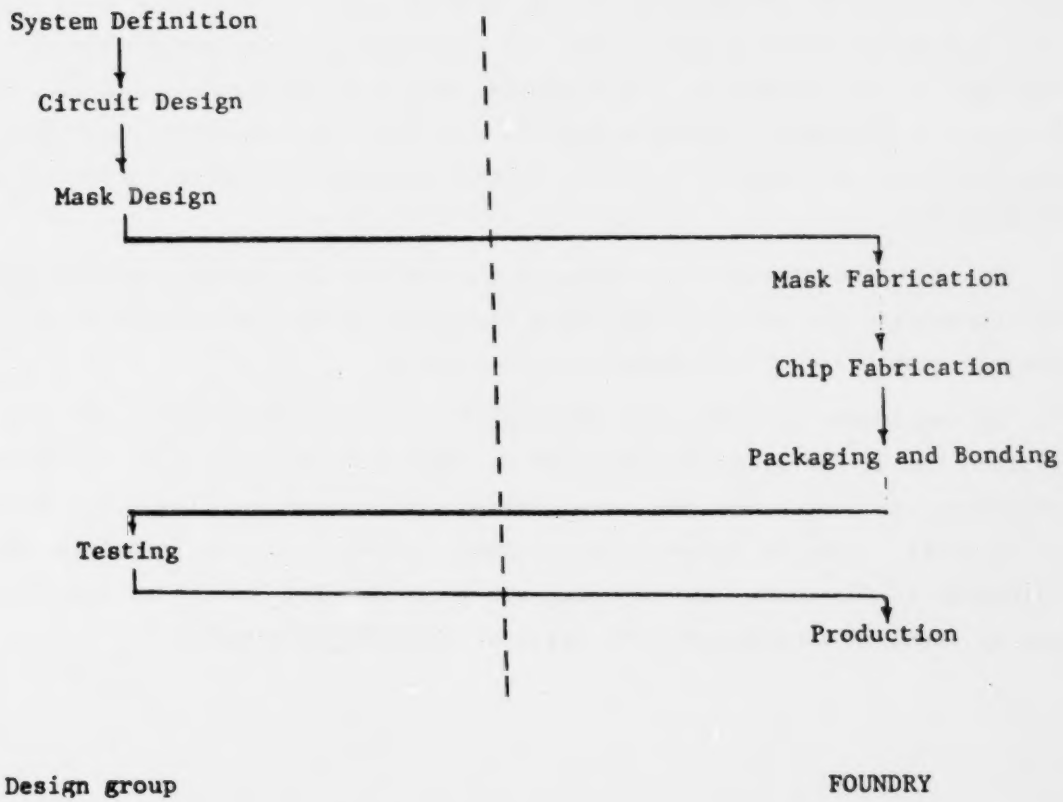
One major characteristic of the integrated circuit industry up until recently has been its vertical integration, at least to the stage of circuit production. There are many steps in the process of going from idea to integrated circuit. The initial steps of system definition, logic design, circuit design and mask design are manpower intensive and "thought intensive" and depend upon having a set of design skills which are almost independent of how the device will actually be made. These steps also establish the eventual function of the device. On the other hand, the later steps: mask fabrication, chip fabrication, bonding and packaging require technical skills and sophisticated equipment and facilities.

However, these steps are in some sense mechanical, in that once the fabrication process has been properly established no changes are required in order to produce a completely different integrated circuit. Nonetheless, because of the enormous capital cost and operating cost of such fabrication facilities only a very few large companies could afford the risk of establishing a fabrication line.

Figure I

TRADITIONAL MICROCIRCUIT DESIGN STEPS

SILICON FOUNDRY APPROACH TO CUSTOM INTEGRATED CIRCUIT DESIGN



The silicon foundry approach to integrated circuit design is aimed at completely restructuring the semiconductor industry in such a way that anyone with an idea can get that idea cast in silicon at a reasonable cost. To achieve this end the "thought stages" associated with design are separated from the "mechanical stages" associated with fabrication (see figure I).

The resulting structure is similar to that found in the hobby photography industry. Someone exposes a piece of film according to a known set of rules. Someone else processes it into the final picture. The film processor doesn't need to know what the pictures are, how they were produced, or what they will be used for. He only needs to know the type of film used. The photographer, on the other hand, doesn't require knowledge of the film processing techniques. He only needs a set of rules given by the film manufacturer about how to expose the film in order to produce safisfactory results. It is also the photographer who tests the results and makes the final judgement of the success of the picture taking exercise.

Essential ingredients in the separation of design from fabrication are a clear set of design rules which, when followed, result in a satisfactory chip and an appropriate data format for communicating the design from the designer to the fabricator. Experiments, mainly at Universities in the United States e.g. Minnesota, Carnegie Mellon, Cornell, and other countries have demonstrated the feasibility of the foundry approach to custom IC design and fabrication.

Standard data formats have evolved which allow the designer and foundry to communicate and sets of simplified design rules have been produced which are manageable even for inexperienced designers.

By the summer of 1982, over 30 companies in the United States offered silicon foundry services for nMos, CMOS, pMOS or bipolar circuits. Limited prototype and production runs were offered with turnaround time being from 4 to 12 weeks. Also in Europe, e.g. in laboratories in Leuven in Belgium and Edinburgh in Scotland, this approach was adopted. The list of silicon foundries can be found in June/August 1983 issue of VLSI DESIGN magazine.

The silicon foundry approach, i.e. to distinguish a design stage and a fabrication stage, could be extremely useful from the developing countries' point of view, if they decide to put together their financial resources aimed at chip production. Microelectronic chip fabrication is a very capital-intensive operation. Very few developing countries would be in a position to establish and operate a chip fabrication facility to make VLSI or even LSI chips. However, several developing countries, for example Argentina, Brazil, India, Mexico, currently have the know-how to undertake the design of chips one part of silicon foundry activity.

There are many reasons for nurturing and promoting this design activity in the developing countries. Firstly, the motivation for producing specific designs could naturally arise only in the developing countries, since the chips for application of the type listed earlier are primarily needed only in these countries, and not in developed countries. Secondly, the possibility of designing customized chips for such applications as these would itself act as an incentive to the rapid absorption and deployment of the micro-electronics technology for development-catalyzing applications. Such a design base, if grown and nurtured, could act as a focus for creative activity in high-quality science and technology. This design activity could generate interest and activity in related fields, e.g. graphics, CAD, software engineering- and so on. In special circumstances. this could even trigger off interest and activity in hardware design and construction to assist the design activity of microelectronics chips. The enormous impetus all these activities would provide to minimize the movement of highly-qualified science and technology professionals from the developing countries to the developed countries (i.e. reversing the brain-drain) is yet another benefit that should be highlighted.

Given that the design of LSI/VLSI chips could be undertaken by the developing countries to meet special application demands. the next stage, converting these designs into actual hardware, i.e. fabrication, may be beyond the means of most developing countries. But if they pull their resources together then the fabrication facility could be established as a joint enter-prise.

There exists a good case for establishing a silicon foundry to meet the customized needs of developing countries Commercial foundries in the western countries would not be able to serve this need for a variety of reasons. Firstly, at least at the initial stages, the foundry would also have to serve as a base for providing know-how. The design teams currently

operating in developing countries are likely to be at varying levels of expertise. Also new design teams would have to be grown to meet the emerging needs of developing countries. Existing commercial foundries obviously would not be in a position to meet these training demands. Even if they are willing to, the costs are likely to be prohibitively high. Secondly, existing commercial foundries are unlikely to be able to devote the capacity needed for meeting the developing countries' needs. Lastly, restrictions imposed by western countries on access to high technology resources in their countries from time to time make existing foundries in these countries not of long-term value to developing countries to meet their needs.

There exists, then, a clear case for establishing a silicon foundry for joint use by developing countries to meet their fabrication needs. For the reasons outlined earlier, the foundry must be a base not merely for fabrication, but for also providing training in, and transferring design know-how. So the establishment should have the capacity in all the design and fabrication stages as sketched earlier. But the design and training could also be established independently in national design focal points of many different countries. Only fabrication should have one location.

What is the technology that such a foundry should cater for? Clearly, it must meet two criteria. It must be a technology that is operationally well understood and can be readily established. It should be able to process wafers of the requisite complexity to meet the kinds of application needs earlier discussed. Both these considerations would suggest MOS technology capable of handling a 2-micron geometry. LSIs and the initial end of VLSIs could be handled by such a foundry immediately. This should serve the needs of the developing countries for the decade of the 1980s. While servicing the needs during this decade using this installed technology, the foundry could equip itself to meet demands involving the next level of sophistication in the 1990s.

This suggestion is reinforced by the following feature of the present world pattern. Out of the total IC market worldwide bipolar and MOS have an almost equal share. However, it must be noted that in terms of LSI/VLSI,

MOS continues to be dominant accounting for over 70 per cent of the LSI market today.

3. Investment Estimates

3.1 Investment for fabrication

Facility investment trends for an IC wafer fabrication production module rises sharply with shrinking feature size. A typical module investment for a self-contained operation designed for a single process technology of 2-micron capability and handling 1500 wafer starts per day, will be approximately $ 60 million today, and even after reducing several parameters, would not be less than $ 30 million.

3.2 Operational costs

There is a fixed minimum cost which is associated with manufacturing of the set of masks required for fabrication and for a production run of one batch of wafers. This cost is in the area of $ 30,000. A single batch of wafers typically produces several thousand identical circuits and thus the cost per circuit is low. However, circuit design always includes at least one prototype run to demonstrate successful operation of the circuit. The cost of a minimum wafer run is the same no matter whether the circuit is a prototype or a proven design. Furthermore, several prototype runs are often required before the design is completely debugged. Thus development costs are still very high. The real difficulty with prototyping is that using the normal procedures you still get several thousand chips from a minimum run when only a few are really required for testing purposes.

There have been several recent innovations which have changed this situation dramatically. The first is what is called a multiproject chip. Each chip on the wafer contains a number of independent prototype designs, usually between five and ten. During the bonding and packaging steps only one circuit on each chip is actually connected to the pins on the package. All other circuits are dormant. However, enough samples of each circuit can be produced from a single wafer run to ensure adequate testing. The cost of the prototype production can therefore be shared by a number of different designers. Even with multiproject chips many more samples are produced than

are actually required. The obvious next step is to produce a set of masks which have many different chip designs on them. Each chip design can still be a multiproject chip. This results in what is called a multiproject wafer. Typically, thirty or forty independent prototype circuits can be produced from one fabrication run with the cost being shared.

One example of the success of this approach is the Australian Multiproject Chip Programme (AUSMPC) coordinated by the CSIRO in Adelaide. Prototype designs have been accepted from universities in Australia and New Zealand, from government research organizations as well as from small industries both in Australia and the United States. Fabrication is carried out at foundries in the United States and Australia. A turnaround time of three months has been achieved and the cost to the designer is around $ 375 per square mm of chip area.

In Canada, a MPC experiment was started in 1980, as a cooperative venture between Queen's University and Northern Telecom Electronics Limited. Because of the success of the effort Northern Telecom offered to provide a foundry service for all Canadian universities and institutes.

Up to the present time, coordination of design submission and distribution of fabricated chips has been handled by Queen's and 12 universities have participated. The success has been so great that an independent. non-profit corporation is presently being established at Queen's to provide the coordinating service. One unique aspect of the programme in Canada is that Northern Telecom offers the fabrication service free of charge to educational institutions in order to encourage improvement in the training of engineering students in the area of integrated circuit design.

4. Training

The most essential ingredient is skilled manpower with background in the areas of system design and circuit design. The detailed knowledge required for the mask design can be acquired relatively rapidly. Graduate students

in electrical engineering at Queen's enter the programme with some system and circuit design experience but with essentially no background in the details of integrated circuit design. During a single 12 week course they not only learn the techniques of design but also produce a prototype design for fabrication. Typically, these designs contain between 1000 and 2000 components and are produced with the aid of a small computer and some very simple computer aided design tools.

One of the initial tasks a designer of custom circuits faces is that of designing the subcircuits, such as gates and registers, which will be combined and used many times to produce the final design. A number of commercial companies have sprung up recently which supply a library of tested standard cells for a variety of different fabrication processes. The designer then has only to select, place and interconnect these standard cells in order to produce a prototype custom design. Design time and therefore development cost are reduced and the design skills required are limited mainly to system design since most of the circuit design is incorporated in the library of standard cells.

5. Conclusions

The Expert Meeting Preparatory to the International Forum on Technological Advances and Development, held in Moscow, 29 November - 3 December 1982, recommended that the UNIDO secretariat should examine the possibility of setting up a task force of experts to examine further the concept of establishing silicon foundries as an instrument for acquiring the capability to manufacture chips for specialized needs.[1/]

The International Forum on Technological Advances and Development, held at Tbilisi, USSR, in April 1983, also considered this issue and recommended that a centre on microprocessor applications should be established to serve national and regional needs. It also suggested that UNIDO should initiate steps to explore the possibility of such a centre, taking into account the needs of the developing countries.[2/]

1/ Report of the Meeting on Technological Advances and Development (ID/WG.384/16).

2/ Report of the International Forum on Technological Advances and Development (ID/WG.389/6).

The ideas on a silicon foundry presented here are of an introductory nature. They show that the establishment of a silicon foundry as a joint developing countries' enterprise seems to be feasible. It would match many articulated needs of the countries and produce chips having application in the specific environment of those countries.

The idea of separation of production facilities located in one selected place from the design, which could be distributed and performed in many different countries, decreases the entry cost for each country. Besides that, national focal point design groups could prepare the designs of chips specifically needed in their countries. The skills acquired by members of these groups could influence the countries' technological development.

However, to transfer these preliminary ideas into an applicable project, a more detailed techno-economic report has to be prepared by UNIDO in co-operation with interested countries.

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THE UNIDO PROGRAMME OF TECHNOLOGICAL ADVANCES:

MICROELECTRONICS

Note prepared by the

UNIDO Technology Programme*

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1. Following the Third General Conference of UNIDO in 1980, a major new programme was established in the Technology Programme of UNIDO dealing with the potentials and implications of technological advances for developing countries. Those advances are not only creating new industries but have substantial implications for a number of other industries. The convergence of these technological advances itself produces an interaction, which in turn has implications for the pattern and rate of industrial production in developing countries. In other words, in planning their industrial development and for achieving the Lima target,[1/] developing countries have to recognize that the present and coming decades are likely to witness substantial changes in production patterns owing to the expected interplay of the new advanced technologies. These technologies have potential as well as limitations for developing countries and it should be part of the industrial and technological strategy of each developing country to see how it can tap the potential of the new technologies without being affected by their limitations.

2. The UNIDO programme on technological advances was designed, in particular, to increase awareness through early identification and assessment and to promote action at national, regional and international levels regarding:

(a) The potential and limitations of various advanced technologies for the developing countries;

(b) The industrial and technological capabilities that the developing countries need in order to be able to use advanced technologies where appropriate and feasible;

(c) The policy actions to be taken by the Governments of developing countries with regard to advanced technologies.

3. In addition to expert group meetings, studies and current awareness bulletins, emphasis has been laid on:

(a) Mobilizing the co-operation of individuals and institutions at the cutting edge of a particular technology;

(b) Promoting national action by developing countries in terms of policies and programmes in accordance with their conditions and requirements;

1/ The Second General Conference of UNIDO, held at Lima, Peru, in March 1975, set a target of a 25 per cent share of world industrial production for the developing countries by the year 2000.

(c) Providing technical assistance, as required by developing countries.

(d) identifying and promoting developing-country-specific applications as also application in various industrial sectors.

4. Activities have been developed within the framework of the foregoing considerations, bearing in mind the nature of the technological advances and the type of practical action that would be most effective in each case.

5. The position in regard to microelectronics is described below briefly, indicating the activities carried out at international, regional and national levels.

Actions by UNIDO at the international level

6. In June 1981 a meeting of experts was organized on the implications of technological advances in microelectronics for developing countries. The meeting emphasized the importance of actions at the national level relating to manufacture, industrial and other applications, software development and the formulation of a national microelectronics strategy. Actions at the international level were also recommended, including a continuous monitoring of observed trends and their impact on various sectors and the development of pilot projects and programmes dealing with applications and software.

7. Following the June 1981 meeting, a mission of experts visited four developing countries in different regions to promote selective applications of microelectronics and software development. Apart form reviewing the national situation in the countries visited, the mission recommended an approach to microelectronics application, including software and suggested models of microprocessor application centres and software houses. Also as a result of the June 1981 meeting, certain activities at the regional level were pursued. These are described in a later section.

8. The International Forum on Technological Advances and Development organized by UNIDO in Tbilisi, USSR in 1983 as well as expert meetings in Moscow, USSR (Dec. 1982), and Dubrovnik, Yugoslavia (June 1983), which respectively preceded and succeeded it, examined the subject of technological advances and development with regard to specific technologies of which

microelectronics was an important one. A suggestion was also made in the Forum that an international centre for microprocessor applications should be established; as a starting point for examining the various requests for regional and international action, a series of country case studies have been initiated, aimed at the national level, but also to identify the scope for regional and international co-operation. It is expected these studies will provide concrete information and meaningful approaches for regional and international action. Studies are under way in Bangladesh, Brazil, India, the Republic of Korea, Pakistan and Venezuela.

9. In an effort to co-ordinate the activities of organizations and professional groups active in the area of information technology for development, the UNIDO secretariat is convening a meeting in Vienna from 21 to 23 March 1984 to bring together representatives of these groups to identify possible areas fo co-operation and consider a mechanism for keeping mutually informed and for formulating joint programmes. In addition to representatives of organizations, selected specialists from developing countries have also been invited to present their countries' policies and requirements. To the meeting will also be presented the concept of 'Technologies for Humanity' which evolved from the International Forum on Technological Advances. The purpose is to formulate and implement programmes addressing problems common to developing countries thereby improving the quality of life of people at large. Microelectronics will be one of the technologies reviewed in this connection.

10. The UNIDO Secretariat has tried to promote the concept of software as an industry and the actions that developing countries could take to promote that industry. The concept has been elaborated through three studies dealing with the importance of software for developing countries; and the approach to software development in those countries; and guidelines for software production. Further work in this area would include the promotion and development of software for specific applications of relevance to developing countries including applications in various industrial sectors. Through these efforts and by other means it is proposed to build up a bank of application software for the benefit of developing countries.

11. Information technology, as covered by the term "informatics" and extending beyond data-bank systems and networks to industrial management tools and industrial processes, is in a stage of dynamic growth, particularly

through the use of microprocessors. UNIDO co-sponsored a Conference on Informatics and Industrial Development with the Irish National Board for Science and Technology and Trinity College, Dublin, in March 1981. The Conference highlighted the importance developing countries attach to information developments, which are of substantial consequence to current industrial development strategies. This subject will be amplified at the future Intergovernmental Conference on Strategies and Policies for Information (SPIN). UNIDO will co-operate with the Intergovernmental Bureau of Informatics in the preparation of the Conference, which will address: the industrial applications of informatics; informatics as a sector of industry per se and hence of relevance to the Industrial and Technological Information Bank of UNIDO; and informatics as a feature of industrial technology in any sector of industry, a factor to be taken into account in the proper selection of advanced technology. UNIDO has also brought out a publication on informatics and industrial development.2/

Regional level activities

12. An Expert Group Meeting for the Economic Commission for Latin America (ECLA) region was held by UNIDO in June 1982 in Mexico, in co-operation with ECLA, at which the socio-economic implications of microelectronic advances for Latin American countries were analysed and a Co-operative Latin American Programme of Action in the field of microelectronics recommended. Follow-up action to draw up such a Co-operative Programme has been initiated by UNIDO and ECLA.

13. As a step in this direction a Latin American Microelectronics Network (REMLA) has been proposed following a high-level expert team mission to Venezuela. At the request of the Government, the experts looked at the facilities of an existing national institution in Venezuela with a view to upgrading it with UNIDO's assistance to become a nodal point for the proposed network. Other nodal points in different parts of the region will be identified.

2/ "Informatics for Industrial Development" (UNIDO/IS.415).

14. A request for assistance has been received from GEPLACEA (Group of Latin American and Caribbean Sugar Exporting Countries) which covers approximately 700 sugar mills in 21 member countries, for assistance in the introduction of microcomputers for optimization of production without too much additional investment. A pilot project will be implemented at a place selected and, if successful, the procedures, software and computing configuration could be utilized for other cane sugar producers.

15. A symposium on Microelectronics for Productivity held at New Delhi in April 1983 and co-sponsored by UNIDO requested UNIDO to take the lead in the promotion of the establishment of an Asian Centre for Electronics. National level studies in selected Asian countries have been undertaken to ascertain the needs for regional co-operation.

16. UNIDO has also co-operated with the Economic Commission for Western Asia (ECWA) in the preparation for and conduct of the Expert Group Meeting on the Development of Microelectronics in the ECWA region, 4-7 March 1984, Kuwait.

17. In regard to Africa, a paper has been prepared as an input to the forthcoming scientists' meeting in Africa, identifying the potentials and limitations of microprocessor applications in Africa and suggesting a programme of action.

National level activities

18. At the national level, apart from the state-of-the-art studies commissioned, the UNIDO secretariat has been assisting the Mexican Government in setting up a permanent national team to monitor technological advances through a project financed by the UNFSSTD. Under this project a national level workshop was held. Thereafter three experts specifically looked at the microelectronics industry in its several aspects and suggested, in the light of the technology trends in the world, the actions that the Mexican Government could pursue.

19. A number of technical assistance projects are being implemented by UNIDO in this field and an illustrative list of these projects is in Annex I.

20. Other activities in this field include: support to a training workshop in Brazil; studies on biomedial applications and power devices prepared on the basis of that workshop and a pilot project for a rural development information system in the state of Karnataka, India; and a field study on computerization of small scale sector industry in India.

Relevant publications isssued by UNIDO

21. The impact of microelectronics has been looked at in UNIDO's programme of industrial studies from the point of view of restructuring world industry. Two studies have been completed: "The impact of microelectronics on the international economic setting: the case of computer-aided design"[3/] "Restructuring world industry in a period of crisis - the role of innovation: an analysis of recent developments in the semi-conductor industry".[4/]

22. A quarterly bulletin, the Microelectronics Monitor, has been published since January 1982 to create awareness and provide current information to a target audience of policy-makers, scientists and technologists, particularly in developing countries. A survey of technological and market trends during the last two years has recently been published by the Monitor.

23. A comprehensive list of documents published so far by the Technology Programme of UNIDO with regard to microelectronics is attached as Annex II.

3/ UNIDO/IS.297

4/ UNIDO/IS.285

Annex I

List of relevant operational technical assistance projects implemented by UNIDO

COUNTRY	PROJECT NUMBER	PROJECT TITLE
Albania	DP/ALB/81/003	Préparation d'un projet de laboratoire d'études dans les domaines de l'automatique et de l'informatique
Brazil	SI/BRA/82/803	Micromechanics/microelectronic interfaces
Bulgaria	DP/BUL/81/002	Strengthening of the Institute for Industrial Cybernetics and Robotics
	DP/BUL/82/001	Assistance to the Automated Production Instrumentation Centre (A.P.I.C.)
	DP/BUL/76/003	Numerical control/computer aided manufacturing, Metalworking Development Centre
	DP/BUL/81/008	NC/CAM Metalworking Development Centre (phase II)
Democratic People's Republic of Korea	DP/DRK/79/003	Establishment of a pilot plant and training centre for bipolar digital integrated circuits
Czechoslovakia	DP/CZE/77/003	Assistance in computer aided design (CAD) and computer aided manufacturing (CAM) in machinery building industries
Ecuador	DP/ECU/78/001	Technical assistance to the industrial and artisanal sector
Egypt	DP/EGY/78/003	Electronic Industries Research and development centre (phase II), electric machinery and equipment

COUNTRY	PROJECT NUMBER	PROJECT TITLE
India	DP/IND/81/025	Development of microprocessor based agro-dairy instruments
	DP/IND/73/014	Establishment of a numerical control centre for metalworking industry (CMTI), Bangalore
	DP/IND/82/033	Computer aided design programme
	DP/IND/82/034	Appropriate automation promotion programme
Libyan Arab Jamahiriya	UC/LIB/83/099	Assistance to the electronics industry
People's Republic of China	DP/CPR/79/020	Computer systems applications
	DP/CPR/80/050	Training and development of micro-computer systems application
Republic of Korea	DP/ROK/75/019	Semiconductor materials technology
	DP/ROK/82/026	Mechanical engineering computer application (MECA) programme (application of CAD/CAM techniques in mechanical industries)
	DP/ROK/82/031	Numerical control centre
Romania	DP/ROM/76/025	Integrated circuit technology
	SI/ROM/79/802	Training centre for microprocessor applications
Viet Nam	DP/VIE/80/039	Electronic and optical maintenance and repair centre
Interregional	UC/INT/83/075	Experts meeting on the application of computer aided design/computer aided manufacturing (CAD/CAM) to developing countries

Annex II

List of documents published by the UNIDO Technology Programme on the Implications for developing countries of advances in microelectronics

Expert Group Meeting on Implications of Technological Advances in Microelectronics for Developing Countries, Vienna, 10-12 June 1981

IS.246 and Corr. 1	Implications of Micro-Electronics for Developing Countries: A Preliminary Overview of Issues.
ME 2	Application of Micro-Eletronics for Development: Issues for Consideration by Sang Joon Hahn.
B.P. 1	Future of Electronics and Technology Transfer by K.V. Ramanathan.
B.P. 2	Large-Scale Integration: Intercontinental Aspects by Ian M. Mackintosh.
B.P. 3	An Overview of the Electronics Industry in Europe by Ian M. Mackintosh.
B.P. 4	From the Second to the Third Industrial Revolution by Gérard Lafay.
B.P. 5	Semiconductor Industry and R+D in India by K.V. Ramanathan.
B.P. 6	Policy and Planning of Computer Education by Shigeichi Moriguchi.
B.P. 7	Experiences Around University Computer Centers by Shigeichi Moriguchi.
B.P. 8	The Software Market - Conditioning Factors and Possible Future Trends. An Analysis Undertaken from a Third World Perspective by Dieter Ernst.
B.P. 9	Potential Application of Computer Conferencing in Less Developed Countries by Carl-Göran Hedén.
B.P. 10	Implications of Micro-Electronics in Developing Countries by Mohammad Aslam.
B.P. 11	Micro-Electronics and Employment by Ernest Braun.
B.P. 12	Futures with Micro-Electronics by Ernest Braun.
B.P. 13	Implications of Technological Advances in Micro-Electronics for Developing Countries: A Suggested Programme of Policy Studies and Action by Dieter Ernst, Kurt Hoffman, Raphael Kaplinsky, Juan Rada and Howard Rush.
UNIDO/IS.242/ Rev.1 and Corr.1	Report on Exchange of Views with Experts on the Implications of Technological Advances in Micro-Electronics for Developing Countries, Vienna, Austria, 10-12 June 1981.

UNIDO/ECLA Expert Group Meeting on Implications of Microelectronics for Developing Countries, Mexico, 7-11 June 1982

ID/WG.372/1	Prospects of Microelectronics Application in Process and Product Development in Developing Countries by Michael Radnor
ID/WG.372/2	Microelectronics and Government Policies: The Case of a Developed Country by Ernest Braun, Kurt Hoffman and Ian Miles.
ID/WG.372/3	Microprocessors and Productivity: Cashing in our Chips by Robert T. Lund.
ID/WG.372/4	Microelectronics and Telecommunications in Latin America by Edgardo Galli.
ID/WG.372/5 and Corr.1	Microelectronics: Its Impact and Policy Implications by Juan F. Rada.
ID/WG.372/6	Potential Applications Suitable for Microprocessor Implementations: Some Illustrative Possibilities by James Oliphant
ID/WG.372/10	Elements for the Formulation of a Regional Programme of Action in the Area of Microelectronics by Carlos Aguirre and Roberto Heredia
ID/WG.372/11	Telecommunications and Microelectronics: Some Observations by E. Galli, M. Welch and R. Herrera.
ID/WG.372/12	The Development of Microelectronics in Argentina by O. Filipello and R. Sagarzazu.
ID/WG.372/13	Cultural Aspects of Microelectronics Technology by Carlos I.Z. Mammana.
ID/WG.372/14	Microprocessor Applications and Industrial Development by Robert T. Lund.
ID/WG.372/15	Microelectronics and the Development of Latin America: Problems and Possibilities for Action by ECLA/UNIDO Joint Industry and Technology Division and Eugenio Lahera and Hugo Nochteff.
ID/WG.372/16	Microelectronics in Peru. Country Monograph by R. Herrera.
ID/WG.372/17	Report, UNIDO/ECLA Expert Group Meeting on Implications of Microelectronics for the ECLA Region, Mexico City, Mexico 7-11 June 1982
UNIDO/IS.230	Technological Perspectives in Machine Tool Industry with special Reference to Micro-Electronics Applications by S.M. Patil.
ID/WG.384/5/ Rev.1	Microelectronics and Developing Countries: Towards an Action-oriented Approach.

ID/WG.401/6 Some Considerations About a Practical Approach to the Development of Technical Infrastructure for Microelectronics by G. Fernandes de La Garza.

UNIDO/IS.331 Prospects of Microelectronics. Application in Process and Product Development in Africa by Michael Radnor.

UNIDO/IS.338 Proceedings of the First Meeting on Co-operation between Scientific and Industrial Sectors in Microelectronics held at Mexico City, 14 and 15 June 1982.

UNIDO/IS.351 Microprocessor Applications for Developing Countries by James Oliphant.

UNIDO/IS.383 Problems of Software Development in Developing Countries.

UNIDO/IS.392 The Impact of Microelectronics on Biomedical Applications in Developing Countries by Cor. L. Claeys.

UNIDO/IS.415 Informatics for Industrial Development by Richard J. Nolan.

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THE UNIDO PROGRAMME OF TECHNOLOGICAL ADVANCES:

MICROELECTRONICS

Note prepared by the

UNIDO Technology Programme*

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1. Following the Third General Conference of UNIDO in 1980, a major new programme was established in the Technology Programme of UNIDO dealing with the potentials and implications of technological advances for developing countries. Those advances are not only creating new industries but have substantial implications for a number of other industries. The convergence of these technological advances itself produces an interaction, which in turn has implications for the pattern and rate of industrial production in developing countries. In other words, in planning their industrial development and for achieving the Lima target,[1/] developing countries have to recognize that the present and coming decades are likely to witness substantial changes in production patterns owing to the expected interplay of the new advanced technologies. These technologies have potential as well as limitations for developing countries and it should be part of the industrial and technological strategy of each developing country to see how it can tap the potential of the new technologies without being affected by their limitations.

2. The Fourth General Conference of UNIDO which took place in Vienna from 2 to 19 August 1984 included an agenda item on the subject of strengthening the scientific and technological capabilities for industrial development in developing countries. In the debate on this item attention was drawn by the secretariat to the changing technological world scene and the consequent need for the developing countries to rectify past deficiencies and to come to grips with the new situation. As technological advances were expected to affect a wide range of industrial sectors, it was necessary for each country to reduce to a minimum the adverse consequences of those advances and to maximize their benefits through a selective and differentiated policy adapted to its own requirements. UNIDO's programme in microelectronics was commended and support was expressed for promoting the establishment of regional and international centres for selected technologies including the networking of existing institutions in the respective regions. Developing countries may identify gaps in existing arrangements with a view to considering setting up national, regional and interregional facilities and networking existing centres including research and development institutions.

1/ The Second General Conference of UNIDO, held at Lima, Peru, in March 1975, set a target of a 25 per cent share of world industrial production for the developing countries by the year 2000.

3. The Conference also recognized that the new technologies will have a wide-ranging impact on industrial development and endorsed the importance of strengthening scientific and technological capabilities for industrial development in developing countries; it urged UNIDO to assist developing countries in building their technological capabilities in different fields of technology including the setting up of national groups to monitor and assess technological trends and the changing international market and promote core groups or institutions in selected technological advances.

4. The concept of promoting specific projects for international co-operation aimed at the betterment of the life of the poorest of the poor, which had originally been formulated at the International Forum on Technological Advances at Tbilisi (USSR) in April 1983, was also presented to the Conference. Its objectives were generally supported and there was agreement that appropriate technologies including advanced ones should be promoted and developed to meet particular needs of a clear urgency to mankind. Microelectronics is a suitable candidate technology as it can be beneficially employed in health care for the rural poor; educational and information purposes in decentralized locations etc.

5. The UNIDO programme on technological advances was designed, in particular, to increase awareness through early identification and assessment and to promote action at national, regional and international levels regarding:

(a) The potential and limitations of various advanced technologies for the developing countries;

(b) The industrial and technological capabilities that the developing countries need in order to be able to use advanced technologies where appropriate and feasible;

(c) The policy actions to be taken by the Governments of developing countries with regard to advanced technologies.

6. In addition to expert group meetings, studies and current awareness bulletins, emphasis has been laid on:

(a) Mobilizing the co-operation of individuals and institutions at the cutting edge of a particular technology;

(b) Promoting national action by developing countries in terms of policies and programmes in accordance with their conditions and requirements;

(c) Providing technical assistance, as required by developing countries.

(d) identifying and promoting developing-country-specific applications as also application in various industrial sectors.

7. Activities have been developed within the framework of the foregoing considerations, bearing in mind the nature of the technological advances and the type of practical action that would be most effective in each case.

8. The position in regard to microelectronics is described below briefly, indicating the activities carried out at international, regional and national levels.

Actions by UNIDO at the international level

9. In June 1981 a meeting of experts was organized on the implications of technological advances in microelectronics for developing countries. The meeting emphasized the importance of actions at the national level relating to manufacture, industrial and other applications, software development and the formulation of a national microelectronics strategy. Actions at the international level were also recommended, including a continuous monitoring of observed trends and their impact on various sectors and the development of pilot projects and programmes dealing with applications and software.

10. Following the June 1981 meeting, a mission of experts visited four developing countries in different regions to promote selective applications of microelectronics and software development. Apart from reviewing the national situation in the countries visited, the mission recommended an approach to microelectronics application, including software and suggested models of microprocessor application centres and software houses. Also as a result of the June 1981 meeting, certain activities at the regional level were pursued. These are described in a later section.

11. The International Forum on Technological Advances and Development organized by UNIDO in Tbilisi, USSR in 1983 as well as expert meetings in Moscow, USSR (Dec. 1982), and Dubrovnik, Yugoslavia (June 1983), which respectively preceded and succeeded it, examined the subject of technological advances and development with regard to specific technologies of which

microelectronics was an important one. A suggestion was also made in the Forum that an international centre for microprocessor applications should be established; as a starting point for examining the various requests for regional and international action, a series of country case studies have been initiated, aimed at the national level, but also to identify the scope for regional and international co-operation. It is expected these studies will provide concrete information and meaningful approaches for regional and international action. Country studies published so far cover Bangladesh, Brazil, India, the Republic of Korea, Pakistan and Venezuela. An overview of the microelectronics industry in these countries has also been prepared.

12. In an effort to co-ordinate the activities of organizations and professional groups active in the area of information technology for development, the UNIDO secretariat convened a meeting in Vienna from 21 to 23 March 1984 which brought together representatives of these groups, identified possible areas of co-operation and considered a mechanism for keeping mutually informed and for formulating joint programmes. In addition to representatives of organizations, selected specialists from developing countries were also invited to present their countries' policies and requirements. As a result of this meeting a Consultative Group on Information Technology (COGIT) has been established which will meet periodically to review ongoing activities, exchange experience and formulate joint programmes. A directory of these groups and organizations will also be prepared by UNIDO which will be updated as new organizations join COGIT.

13. The UNIDO Secretariat has tried to promote the concept of software as an industry and the actions that developing countries could take to promote that industry. The concept has been elaborated through three studies dealing with the importance of software for developing countries; the approach to software development in those countries; and guidelines for software production. Further work in this area would include the promotion and development of software for specific applications of relevance to developing countries including applications in various industrial sectors. A report on the commercialization of software: main issues and contractual terms and conditions, was prepared and submitted to the Ninth Meeting of Heads of Technology Transfer Registries. Through these efforts and by other means it is proposed to build up a bank of application software for the benefit of developing countries.

14. Information technology, as covered by the term "informatics" and extending beyond data-bank systems and networks to industrial management tools and industrial processes, is in a stage of dynamic growth, particularly through the use of microprocessors. UNIDO co-sponsored a Conference on Informatics and Industrial Development with the Irish National Board for Science and Technology and Trinity College, Dublin, in March 1981. The Conference highlighted the importance developing countries attach to information developments, which are of substantial consequence to current industrial development strategies. This subject will be amplified at the future Intergovernmental Conference on Strategies and Policies for Information (SPIN). UNIDO will co-operate with the Intergovernmental Bureau of Informatics in the preparation of the Conference, which will address: the industrial applications of informatics; informatics as a sector of industry per se and hence of relevance to the Industrial and Technological Information Bank of UNIDO; and informatics as a feature of industrial technology in any sector of industry, a factor to be taken into account in the proper selection of advanced technology. UNIDO has also brought out a publication on informatics and industrial development.2/

Regional level activities

15. An Expert Group Meeting for the Economic Commission for Latin America and the Caribbean (ECLAC) region was held by UNIDO in June 1982 in Mexico, in co-operation with ECLAC, at which the socio-economic implications of micro-electronics advances for Latin American countries were analysed and a Co-operative Latin American Programme of Action in the field of microelectronics recommended. Follow-up action to draw up such a Co-operative Programme has been initiated by UNIDO and ECLAC.

2/ "Informatics for Industrial Development" (UNIDO/IS.415).

16. As a step in this direction a Latin American Microelectronics Network including the Caribbean (REMLAC) has been proposed following a high-level expert team mission to Venezuela in 1983. At the request of the Government, the experts looked at the facilities of an existing national institution in Venezuela with a view to upgrading it with UNIDO's assistance to become a nodal point for the proposed network. Other nodal points in different parts of the region will be identified. A meeting will take place in June 1985 in Caracas to establish REMLAC and to develop a programme of co-operation among the participating countries.

17. A request for assistance has been received from GEPLACEA (Group of Latin American and Caribbean Sugar Exporting Countries) which covers approximately 700 sugar mills in 21 member countries, for assistance in the introduction of microcomputers for optimization of production without too much additional investment. A pilot project will be implemented at a place selected and, if successful, the procedures, software and computing configuration could be utilized for other cane sugar producers.

18. A symposium on Microelectronics for Productivity held at New Delhi in April 1983 and co-sponsored by UNIDO requested UNIDO to take the lead in the promotion of the establishment of an Asian Centre for Electronics. National level studies in selected Asian countries have been undertaken to ascertain the needs for regional co-operation.

19. UNIDO has also co-operated with the Economic Commission for Western Asia (ECWA) in the preparation for and conduct of the Expert Group Meeting on the Development of Microelectronics in the ECWA region, 4-7 March 1984, Kuwait. Recommendations made at that meeting requested UNIDO inter alia to look into the possibility of establishing a silicon foundry with design facilities in the ECWA region. A UNIDO consultant undertook a preliminary mission in December 1984 which will be followed up by an in-depth study of the potentiality of future products in the countries of the region to assess the scope and potential in the region of the local manufacturing. Another co-operative effort between ECWA and UNIDO is the promotion of a CAD/CAM programme and its introduction in industry in the region. A report has been prepared by a UNIDO consultant.

20. In regard to Africa, UNIDO co-sponsored with UNCSTD, OAU and ECA a meeting of African scientists on the implications of new technologies in the implementation of the Lagos Plan of Action and the programme for the Industrial Development Decade for Africa. The meeting was held in Mbabane, Swaziland, from 22 to 26 October 1984.

21. A national meeting on applications of microelectronics and software is being organized by UNIDO in Kenya and will take place from 18 to 23 February 1985. Representatives from countries of the region such as Ethiopia, Sudan, Tanzania, Uganda and Zambia will also attend. Members of COGIT will participate as observers and sponsor an exhibition of their activities and specific products developed by them.

National level activities

22. At the national level, apart from the state-of-the-art studies commissioned, the UNIDO secretariat has been assisting the Mexican Government in setting up a permanent national team to monitor technological advances through a project financed by the UNFSSTD. Under this project a national level workshop was held. Thereafter three experts specifically looked at the microelectronics industry in its several aspects and suggested, in the light of the technology trends in the world, the actions that the Mexican Government could pursue.

23. A number of technical assistance projects are being implemented by UNIDO in this field and an illustrative list of these projects is in Annex I.

24. Other activities in this field include: support to a training workshop in Brazil; studies on biomedial applications and power devices prepared on the basis of that workshop; a pilot project for a rural development information system in the state of Karnataka, India; and a field study on computerization of small scale sector industry in India. A study on the use of computers for the organization of meat production and processing based on the experience gained from the system in the Philippines is under preparation.

Relevant publications isssued by UNIDO

25. The impact of microelectronics has been looked at in UNIDO's programme of industrial studies from the point of view of restructuring world industry. Two studies have been completed: "The impact of microelectronics on the international economic setting: the case of computer-aided design"[3/] "Restructuring world industry in a period of crisis - the role of innovation: an analysis of recent developments in the semi-conductor industry".[4/]

26. A quarterly bulletin, the Microelectronics Monitor, has been published since January 1982 to create awareness and provide current information to a target audience of policy-makers, scientists and technologists, particularly in developing countries. A survey of technological and market trends during 1982 - 1983 has been published by the Monitor.[5/] A special supplement reviewing developments in flexible manufacturing systems (FMS) will be published in February 1985.

27. A comprehensive list of documents published so far by the Technology Programme of UNIDO with regard to microelectronics is attached as Annex II.

3/ UNIDO/IS.297

4/ UNIDO/IS.285

5/ UNIDO/IS.438

Annex I

List of relevant operational technical assistance projects implemented by UNIDO

COUNTRY	PROJECT NUMBER	PROJECT TITLE
Albania	DP/ALB/84/001	Electronic instrumentation, automation and process control development
Brazil	SI/BRA/82/803	Micromechanics/microelectronic interfaces
Bulgaria	DP/BUL/81/002	Strengthening of the Institute for Industrial Cybernetics and Robotics
	DP/BUL/81/008	'Numerical control/computer aided manufacturing (NC/CAM) Metalworking Development Centre' (phase II)
	DP/BUL/81/009	Advanced manufacturing and engineering methods
	DP/BUL/82/001	Automated Production Instrumentation Centre (A.P.I.C.)
	UC/BUL/84/117	Assistance to the introduction of micro-electronics in industry
Czechoslovakia	DP/CZE/77/003	Assistance in computer aided design (CAD) and computer aided manufacturing (CAM) in machinery building industries
Democratic People's Republic of Korea	DP/DRK/79/003	Establishment of a pilot plant and training centre for bipolar digital integrated circuits
	DP/DRK/81/010	Numerically controlled machine tools, equipment and methods
	DP/DRK/81/016	Assistance to the Institute of Automation in computerized technology for automation in industrial applications
	DP/DRK/84/001	Development of numerically controlled machine-tools

COUNTRY	PROJECT NUMBER	PROJECT TITLE
Egypt	DP/EGY/78/003	Electronic Industries Research and Development Centre (phase II), electric machinery and equipment
Hungary	DP/HUN/82/003	Introduction of computer aided design training and education
India	DP/IND/81/025	Development of microprocessor based agro-dairy instruments
	DP/IND/82/024	Microprocessor application engineering programme
	DP/IND/82/033	Computer aided design programme
	DP/IND/82/034	Appropriate automation promotion programme
	DP/IND/84/015	Semiconductor devices and electronics sub-systems for transportation
	DP/IND/84/030	Microprocessor application engineering programme
	UC/IND/84/184	Electronics PCB Development
People's Republic of China	DP/CPR/80/050	Training and development of microcomputer systems application
Poland	RP/POL/84/001	Computer graphics implementation into the computer aided design and computer aided manufacturing in the Polish machine building industry
Republic of Korea	DP/ROK/75/019	Semiconductor materials technology
	DP/ROK/82/026	Mechanical engineering computer application (MECA) programme (application of CAD/CAM techniques in mechanical industries)
	DP/ROK/82/031	Numerical control centre
Interregional	UC/INT/84/125	Group training programme in computer aided design (CAD) and in computer aided manufacturing (CAM), Prague, CSSR, 10 - 29 September 1984

Annex II

List of documents published by the UNIDO Technology Programme on the Implications for developing countries of advances in microelectronics

Expert Group Meeting on Implications of Technological Advances in Microelectronics for Developing Countries, Vienna, 10-12 June 1981

IS.246 and Corr. 1	Implications of Micro-Electronics for Developing Countries: A Preliminary Overview of Issues.
UNIDO/IS.242/ Rev.1 and Corr.1	Report on Exchange of Views with Experts on the Implications of Technological Advances in Micro-Electronics for Developing Countries, Vienna, Austria, 10-12 June 1981.

UNIDO/ECLA Expert Group Meeting on Implications of Microelectronics for Developing Countries, Mexico, 7-11 June 1982

ID/WG.372/1	Prospects of Microelectronics Application in Process and Product Development in Developing Countries by Michael Radnor
ID/WG.372/2	Microelectronics and Government Policies: The Case of a Developed Country by Ernest Braun, Kurt Hoffman and Ian Miles.
ID/WG.372/3	Microprocessors and Productivity: Cashing in our Chips by Robert T. Lund.
ID/WG.372/4	Microelectronics and Telecommunications in Latin America by Edgardo Galli.
ID/WG.372/5 and Corr.1	Microelectronics: Its Impact and Policy Implications by Juan F. Rada.
ID/WG.372/6	Potential Applications Suitable for Microprocessor Implementations: Some Illustrative Possibilities by James Oliphant
ID/WG.372/10	Elements for the Formulation of a Regional Programme of Action in the Area of Microelectronics by Carlos Aguirre and Roberto Heredia
ID/WG.372/11	Telecommunications and Microelectronics: Some Observations by E. Galli, M. Welch and R. Herrera.
ID/WG.372/12	The Development of Microelectronics in Argentina by O. Filipello and R. Sagarzazu.
ID/WG.372/13	Cultural Aspects of Microelectronics Technology by Carlos I.Z. Mammana.
ID/WG.372/14	Microprocessor Applications and Industrial Development by Robert T. Lund.

ID/WG.372/15	Microelectronics and the Development of Latin America: Problems and Possibilities for Action by ECLA/UNIDO Joint Industry and Technology Division and Eugenio Lahera and Hugo Nochteff.
ID/WG.372/16	Microelectronics in Peru. Country Monograph by R. Herrera.
ID/WG.372/17	Report, UNIDO/ECLA Expert Group Meeting on Implications of Microelectronics for the ECLA Region, Mexico City, Mexico 7-11 June 1982

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UNIDO/IS.230	Technological Perspectives in Machine Tool Industry with special Reference to Micro-Electronics Applications by S.M. Patil.
ID/WG.384/5/ Rev.1	Microelectronics and Developing Countries: Towards an Action-oriented Approach.
ID/WG.401/6	Some Considerations About a Practical Approach to the Development of Technical Infrastructure for Microelectronics by G. Fernandes de La Garza.
UNIDO/IS.331	Prospects of Microelectronics. Application in Process and Product Development in Africa by Michael Radnor.
UNIDO/IS.338	Proceedings of the First Meeting on Co-operation between Scientific and Industrial Sectors in Microelectronics held at Mexico City, 14 and 15 June 1982.
UNIDO/IS.351	Microprocessor Applications for Developing Countries by James Oliphant.
UNIDO/IS.383	Problems of Software Development in Developing Countries.
UNIDO/IS.392	The Impact of Microelectronics on Biomedical Applications in Developing Countries by Cor. L. Claeys.
UNIDO/IS.415	Informatics for Industrial Development by Richard J. Nolan.
UNIDO/IS.438	Technology and Market Trends in the Production and Application of Information Technology by John Bessant
UNIDO/IS.439	Guidelines for Software Development in Developing Countries by R. Narasimhan
UNIDO/IS.440	Guidelines for Software Production in Developing Countries by H. Kopetz
UNIDO/IS.444	A Silicon Foundry to Service Developing Countries' Needs: A Preliminary Approach by the UNIDO secretariat

UNIDO/IS.446	Software Engineering: A Survey by W. Turski
ID/WG.419/1	Microelectronics Applications for Developing Countries: Preliminary Issues for Concerted Action
ID/WG.419/13	Report of Discussion Meeting on Information Technology for Development
UNIDO/IS.489	State-of-the-Art Series on Microelectronics No. 1 Venezuela No. 2 India No. 3 Republic of Korea No. 4 Pakistan No. 5 Bangladesh
UNIDO/IS.500	Overview of the Microelectronics Industry in Selected Developing Countries by S.E. Lalor

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SOFTWARE ENGINEERING: A SURVEY

by

Wladyslaw M. Turski**
UNIDO Consultant*

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** Professor, Institute of Informatics, Warsaw University, and Department of Computing, Imperial College, London.

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1. The term "software engineering" was coined at the same time and at the same conference which brought into the open the deep concern with the growing software crisis. The conference was held in 1968. The chief symptoms of the software crisis were: software unreliability, delays in meeting promised delivery time for software systems, difficulties in achieving desired functionality and performance of software, complexity of software systems and their resistance to modification attempts, shortage of skilled programmers and - above all - alarming cost of software development and maintenance.

2. The last fifteen years saw a dramatic decrease in the cost of all imaginable units of raw computing power: the dollar-per-KB and dollar-per-MIPS measures are falling in absolute terms, let alone discounted for inflation. Parallel to this trend, although running in the opposite direction, is a very rapid increase in hardware capabilities and availability. A fixed amount of money buys not only much more hardware today than 15 years ago, it also buys a much more sophisticated equipment. Software difficulties, then seen as a bottleneck in computer applications, have become the most important limiting factor today. For all practical purposes , the software costs are the foremost consideration when a new application system is contemplated. The policy of buying hardware to run available software systems has become almost the industry rule. The accumulated investment in software is already staggering and grows world-wide by some 10^{10} - 10^{11} US$ per year.

3. It should, therefore, come as no surprise that a very considerable effort is being put into improved methods of software design, implementation and maintenance. Qualified programmers being scarce the world over, assorted software tools, increasing the programmers productivity by automation of the more routine aspects of their work, are considered a very promising means of alleviating the software crisis.

4. In this report we shall survey the main directions of software engineering - a discipline of producing better software more economically. (It is important to consider both aspects simultaneously: making software cheaper at the expense of its quality is just as absurd as improving its quality at a disproportionate increase in costs).

The change in approach

5. Arguably the most important change in the whole software scene over the last 15 years is the emergence of consensus on the issue of software correctness. It is by now universally accepted that correctness is the main criterion of software quality: no matter how good a piece of software is in all other respects (such as efficiency or robustness), if it is incorrect its value is nil. Without an accepted notion of what constitutes the correctness of software, the insistence on software being first of all "correct" would be meaningless.

6. A very useful notion of software correctness has been found in the logical notion of satisfaction that may exist between two formal systems. Roughly speaking, a system S satisfies system T if whatever follows from system T is a fact in system S. In more rigorous terms, we say that S satisfies T if there exists an interpretation I: T - S such that to each statement t deemed true in T the interpretation I assigns a provably true statement s in S: (t = true in T) implies (s = I(t) = true in S). In practical terms, T is what constitutes a specification, S - the software.

7. For example, statement t may say that SORT(x) is the sequence X rearranged so that its members are put in ascending order. Statement s may take a form CALL PROC SHELL(INPUT(A)). If now the interpretation I is such that PROC SHELL is the name of the Shell-sort routine, CALL denotes an invocation of a routine, A is the name of a file, INPUT - an operation delivering the file listed as its parameter, then all that is needed to establish that s satisfies t is to prove - from the particular description of Shell-sort - that indeed its execution delivers the sorted version of its input parameter.

8. Two observations are in order:

(a) Using the outlined approach we assume that the specification correctly reflects the user's requirements.

(b) It is a matter of formal calculations to establish if a given software satisfies the given specification.

9. The first of these observations clearly indicates that the burden of somehow verifying whether or not the software meets the application needs is shifted from programming to specification analysis. The second one presents in a nutshell the methodological advance which is the cornerstone of software engineering: given the specifications, the correctness of remaining parts of the design and implementation process becomes a calculable question.

10. We shall return to the specification issue later. Now, we shall consider the significance of correctness calculability.

11. First attempts to exploit the notion of calculable correctness concentrated around programme verification, i.e. around a process which would take a specification and a programme, and - based on this information alone - would attempt to calculate if the programme is correct. This approach has had a limited success only: the amount of formal calculations involved was formidable even in the case of pretty small programmes. For large programmes it became prohibitive, even if human intervention was allowed to speed up some of the calculations.

12. Soon it transpired that a much better policy to exploit the notion of calculable correctness is to devise such programming techniques which would guarantee programme correctness by virtue of the very construction process. Thus methods of building correct programmes from specifications started to appear.

Specification-based methods of programming

13. Common to these methods is the view of specification as the most abstract description of all desired properties of the desired software. (By "most abstract" here we mean "free of all unnecessary detail".) The software design and implementation is seen as a process of transforming such abstract description, by adding necessary details, into a programme which is to preserve all properties contained in the specification. (Thus the main difference between the specification and the corresponding programme is that of detail: the specification is free of machine-oriented details but, of course, contains all application-oriented ones.)

14. Methods which pursue this approach are known as top-down design methodologies, a name which refers to the fact that - after the software is successfully designed and implemented - the history of the construction process is not unlike a pyramid with the original specification occupying its summit and the working version of the implemented software being its base. When one ascends this pyramid (moving as it were in the direction opposite to that which the designer took) one sheds the implementation and design details until the refined, most abstract summit - the specification - is reached.

15. Basically, the top-down programming methodology consists in repeated application of the following procedure:

(a) Given a problem P, is it possible to express its solution in a reasonably concise fashion using primitive notions of the linguistic level at which we want to programme? If yes, write the programme, if not, invent notions P1, ..., Pn such that

(i) each of the notions P1, ..., Pn is well-specified,

(ii) using these notions according to their specification it is possible to write a satisfactory programme for problem P.

(b) Consider each of the notions P1, ..., Pn in turn as a new problem and repeat the procedure.

This problem continues until all invented notions are implemented in terms of primitives of the given programming level.

16. The above given brief description of the top-down design and implementation methodology introduces two important techniques: that of structured programming (or structured decomposition) and that of stepwise refinement. We rely on the first one when we decompose problem P into problems P1, ..., Pn, and on the other one when we consider each of the P1,..., Pn as a new problem in itself, to be solved by the same method.

17. Both techniques rely on sound mathematical principles which guarantee their correctness if certain rules of decomposition and refinement are observed. Consideration of the mathematical foundations of structured programming and stepwise refinement have led to new concepts in programming languages, such

as ADA, PASCAL or MODULA. These modern programming languages are designed explicitly so as to facilitate, and even in some instances: enforce a disciplined use of these techniques. It should be observed that while no programming language per se ever solves any software design problem, the use of a tool influences the way in which its user works. Programming languages of yesteryears, FORTRAN, COBOL and BASIC lack the mechanisms to support structured programming and stepwise refinement. In such languages it is virtually impossible and certainly very awkward to use the techniques which emerged as the most common tool of modern software engineering.

Approaches to specification of software

18. It has been firmly established that the early stages of software system design are crucial for the eventual system usefulness. This observation is, of course, directly related to the fact that it is precisely the specification which in the final count is taken as the frame of reference in which software correctness is established. Thus, all design/implementation techniques respecting the notions of correctness cannot but preserve any specification errors. Consequently, such errors become apparent only after the software has been implemented and thus are very expensive to correct. This clearly underscores the need to verify specifications, both from the point of view of their implementability and from the point of view of their relevance for the intended application.

19. The verification of specifications with respect to their relevance poses a very subtle question of translation between (often fuzzy) intentions of the eventual user and (necessarliy formal) expression of specifications. Many techniques have been proposed specifically oriented towards easing of this task. In essence, these techniques assume that the prime author of the specifications is the eventual user, and - by providing a somewhat restrictive means of expression - force him to express his intentions in a form that can be easily manipulated by formal methods. Often such techniques depend on graphic conventions (e.g. SADT), whereby the user/author is pressed to describe his ideas in form of pre-designed and partially labelled diagrams. Freely added, user-invented lables express his intentions originally just by their mnemonic significance. Gradually, as the specifier is asked to complete more

detailed diagrams, the pre-designed structural dependencies between diagrams are explored by a "hidden" analyser, which brings to the open all inconsistencies and many instances of design incompleteness.

20. An entirely different approach to specification writing can be exemplified specification languages (such as CLEAR). In this approach, the recognition that a specification is in fact a formal theory of an application domain is made into the main tenet and main mental tool as well. Specification languages provide means for relatively easy-to-read description of theories and - more significantly - for combining thus described theories into larger ones. For example, given a formulation of a theory of optimality (for instance by means of linear programming principles) and a formulation of a theory of control of a chemical process, their combination will yield a formulation of a theory of optimal control of this process. (Naturally, not any two theories can be combined, it is up to the specification language designers to make sure that any combination expressible in the language "makes sense" and that absurd combinations would be inexpressible; exactly as in safe programming language it is impossible to execute sin(true) instruction.)

21. When many useful application domain concepts are captured by corresponding theories, a specification language may be indeed very useful: the specification of a concrete system may be obtained by a combination of "library theories" with some specific expressions written just for this system. The main advantage of this approach, apart from economy of design, is in the increased safety: library theories are known to be safe and the language includes many safety measures which make it unlikely that the nonsensical combinations would be expressed by mistake.

22. Both graphic and linguistic approaches to formal specification writing are well founded in deep theoretical research into such issues as abstract data types, algebraic theories, theory of models etc. The same kind of foundations are used by a number of software description techniques, such as VDM, commonly used for unambiguous definition of large software products, such as semantics of new programming languages (CHILL, ADA) or special software systems (CICS).

Software life-cycle

23. A software system written for a particular application seldom can be used for an extended period without undergoing a number of changes. Among the many causes that necessitate software changes one can list the following:

(a) The nature of the application itself changes (e.g. for a banking application, the introduction of EFT facility changes dramatically the accounting procedures).

(b) New hardware elements are added to the system and need to be incorporated into the class of devices supported by the software (e.g. colour screens are introduced into a system that used monochromatic screens only: a new "dimension" must be added to all output and, perhaps, input functions).

(c) An existing piece of saftware is transferred to another environment, or the environment itself changes (e.g. better educated operators are hired, for whom the existing input procedures are too dull; new input procedures are required which would make the operators' task more appealing to new staff).

(d) The scope of the application is enlarged (e.g. in a hospital computer system the intensive-care unit computer services are to be linked to a previously separate medical record system).

(e) The requirements placed on the existing system are changed (e.g. the air-traffic control system must be modified when the airport it serves starts accepting faster jets and thus the decision time must be reduced to accommodate the faster traffic).

The list of causes can be, no doubt, extended. Even this incomplete list is sufficient to draw the unavoidable conclusion: changes in a live system are indeed necessary, quite apart from any remedial changes due to its detected stortcomings and internally motivated software improvements.

24. An unfortunate tradition lumps under the title "software maintenance" all activities related to software changes occurring after the original system has been successfully installed. It is important to remember therefore that software maintenance is needed not because software deteriorates in use

(there is, of course, no wear and tear of software), but because its use for a dynamically changing application will be diminished unless the software is modified.

25. In fact, the usual presentation of software life-cycle contains four major phases:

(a) Conception
(b) Design
(c) Implementation
(d) Maintenance.

26. Largely due to the fact that the "maintenance" comprises future modifications, its share in the total expenditure is very large. In many cases the maintenance costs constitute more than three-quarters of the total investment in a software system. (This is a very important observation: a client buying a moderately-sized software system for, say $ 100,000 should not be surprised that the maintenance costs over the next few years will run up to $ 300,000. If he is not prepared to pay this "extra", almost certainly he will find himself tied to an ever decreasing useful piece of software. If he tries to economize, e.g. by assigning junior staff to maintenance activities, he may face a total disaster - the system may become hopelessly entangled and virtually useless.)

27. The main reason for the high cost of software maintenance is the (abundantly confirmed by many a post-mortem analysis) fact that the complexity of software grows very rapidly with every change made to the original version, unless a conscious redesign efforts (also expensive) is made to reduce the complexity. Thus, each subsequent change is harder to make and is more likely to introduce - in addition to the desired ones - many unforseen and often inpleasant effects.

28. These observations lead to two inter-related software engineering problems:

(a) How to design software in such a way that it would be relatively easy to modify?

(b) How to modify an existing software so as not to increase its complexity more than absolutely necessary?

29. The first of these issues is answered by modular and hierarchical design. The second - by controlled backtracking techniques - greatly facilitated by well-designed programming support environments.

Modular design

30. A very general engineering principle calls for the final product to be assembled from easily replaceable parts. Thus a bicycle consists of a frame, two wheels, pedals, chain etc. If the bicycle malfunctions, the cause of the trouble can usually be traced to one of these parts, and the faulty part can be replaced by another of the same type or, indeed, by any similar part which fits. It is not unusual for a bicycle to have wheels of different make than the frame or even two different pedals. As long as the parts satisfy certain externally specified interface requirements, their internal construction is of secondary importance. Thanks to this principle, we may put snow tyres on our cars, thus obtaining a vehicle with rather different driving parameters, without actually having to change the engine or steering wheel.

31. This general engineering principle translates in software design into a requirement according to which any software product should be built from relatively independent modules. Each module meets its specifications if it is a correct module; a module specification is all that is externally known about the module. The functionality of the whole system obtains from the interaction of modules, the interaction itself being fully determined by modular interfaces.

32. When designing a piece of software, one decomposes the design into a number of relatively independent units - modules. Having listed the external properties of each module, i.e. having formulated each module specification, one can prove the appropriateness of the decomposition by proving that the required properties of the whole indeed follow from the postulated properties of modules. This being established, each module in turn may be considered a new designing problem. Thus, allowing for hierarchy of modules, we see a complete analogy with the stepwise refinement technique, although this time the technique is expressed in terms of structured components of programmes.

33. A well modularized programme can be now relatively easily changed by replacement of a module by another, the fresh module sharing with the old one its interface specification, while differing in secondary considerations, i.e. in those which are not covered by the specification relied upon in the overall design. For instance, if we want to adapt our software to exploit the potentials offered by a new output device, we can concentrate on the output module in which all relevant aspects of the given piece of software should be encapsulated.

34. Naturally enough, not any haphazard hacking of the design into pieces can be considered a proper modularization. Sound engineering principles of modular design have been formulated, which facilitates making correct modularization decisions. The same principles ensure that a majority of errors can be localized within a module, thus the repair activities may usually be limited to a single module.

35. Since a module can by replaced by any other module provided their functional specifications and interface characteristics match, there is a huge incentive to plan libraries of interchangeable modules, rather like a Mechano set, from which a variety of software products could be rapidly constructed. Modules that could be used in many different programmes are known as reusable ones, and all successful software houses possess substantial libraries of reusable modules from which a major part of any system within the specialization area of the house can be constructed.

36. Some modern programming languages, notably ADA and MODULA, actively encourage modular programming. ADA, for example, was explicitly designed to permit independent compilation of modules, so that libraries of reusable, precompiled modules bay be accumulated.

37. A number of design methods have been proposed which are based on the modular programming principle. Some of these are commercially available as kits consisting of a large number of tools, i.e. special programmes which assist programmers in their work on software design and implementation. In general, such commercially available methods concentrate on a chosen guiding principle for modularization (e.g. data flow, calling hierarchy or input/output

transformation) which suggests a particular approach to structuring the design. Identified modules are named and their main characteristics are specified. Then, the use of supplied tools enables one to display the emerging design in a coherent way and - more importantly - to check the consistency of the design by verifying that the specified properties of the modules placed in their respective structural positions indeed correspond to each other. Thus, for instance, if it follows from the design structure that a module M imports data named x, it is possible to check that there is at least one other module which exports thus named data. Having identified such a module, say N, it is possible to check if modules M and N are structurally related in such a way that data transfer between them is allowed. Similarly, it may be checked if data z, generated by a module K, is imported by any other module or presented as a system output.

38. Most available tool-assisted modularization methods allow many such consistency checks to be run at several levels of detail, thus permitting to verify at least some aspects of the design before any detailed programming (on intramodular level) is done.

39. Another useful extension of modular programming techniques consists in substituting module surrogates for not yet implemented modules. Thus, as the implementation progresses, one can animate the complete system even if only a part of its modules is actually coded: the remaining modules being replaced by surrogates, the whole system may be made to perform. Such animated execution allows to check some external properties of the system long before its implementation is completed and therefore to avoid at least some unpleasant surprises and - perhaps - to introduce design modifications before they become prohibitively expensive to carry out.

Software modification

40. Assuming that we have a well designed and correctly implemented piece of software, any subsequent modification should start with a clearly specified request for modification. If the history of the design is preserved (and again there are special software tools constructed specifically for the purpose of storing the software design history in a manageable form), it is

possible to identify the design step at which the decisions contrary to the requested modification were made. (Such a step must always be there since otherwise the request could be met by the existing software and thus no real change would be in fact requested although the request may still have led to some programming, e.g. of an add-on extension of the available software.) As soon as the pertinent design step is identified we know that all preceding steps can be safely preserved in the new design, i.e. in the design aimed at satisfying the considered change request. If the subsequent steps of the old design are discarded, the incorporation of the requested modification may be viewed as a continuation of the preserved part of old design by a suitable sequence of the new design steps.

41. If there are many such modification requests, we are soon faced with a "forest" of designs - from each design step at which some change has been incorporated a new branch is started. A suitable "navigation" tool is needed if the programmer is to be able to traverse freely the design "forest" and collect design steps along each particular branch. Again, such tools are commercially available.

42. The main objective of controlling the software modification may be stated as a stability problem for software development: how to achieve the situation in which small changes in specification could be accommodated by small changes in the implemented software.

43. No general solution of this problem is known (and, according to many experts, such general solution may never be discovered). There exist, however, some design/implementation techniques which admit a partial solution of the stability problem.

44. For instance, if every time an arbitrary decision is made (selecting a particular branch) all feasible although discarded decisions are duly recorded and preserved in the design data base, subsequent design steps may include a "what if" analysis, forcing the programmer not to do anything detrimental to implementation of the rejected options. or - at the very least - to clearly mark subsequent decisions with comments informing about such past options which from now on become infeasible. If the design history is decorated with such comments, a change request may be run against the tree of rejected

alternatives, yielding not only the level to which the design is to be backtracked, but also informing about the point at which the incorporation of the requested change became infeasible in the present implementation. Analysis of this information permits to guess roughly the amount of redesign effort needed to make the change. Changes that would require too much effort may be then rejected, or - if undertaken - may be explicitly marked as difficult-to-implement and therefore expensive. It should be stressed once more that a proper management of software modification and change requests is probably the most important aspect of software engineering as it is this phase of the software life-cycle in which the lion's share of the total expense is incurred. The general approach outlined above may be viable only if during its entire life-cycle a software system is supported by a comprehensive design and development documentation in which all versions and mutations are recorded in a manner allowing for a relatively easy restoration of arbitrary past states. It goes without saying that if such a support is to be of real assistance to programmers, it must provide the relevant information in a form that permits machine-assisted manipulation of a large number of variants. Thus again we are led to consider the importance of software tools.

Software tools

45. There are several varieties of software tools more or less available on the market, many more tools are the property of software houses which use them for their internal purposes.

46. Probably the most common among commercially available tools are all sorts of editors, i.e. programmes that facilitate programme composition and programme text manipulation at a programmer's work station (e.g. on a VDU). The editors range from pretty simple text manipulators to quite sophisticated, programming-language oriented structured editors that in addition to the facilities provided by plain text editors include an active mode of assistance. In the latter mode, structured editors prompt the programmer as to proper instruction formats, check for syntactic completeness of phrases, warn against simple context-detectible errors etc. Nearly all varieties of programming editors take care of simple yet laborious editing operations, such as textual substitutions, systematic renaming of programming objects etc. Many newer programming editors are geared to exploit display facilities offered by modern

terminals, e.g. by providing the so-called multiwindow option, whereby a programmer may divide the screen into several independent "windows", conducting in each of them a separate programme (or programme part) development. Thus, for example, a programmer may develop the main programme in one window, a subrouting in another and an input/output handler in yet another. A fourth window may be used for display of pertinent parameters, such as the number of lines of code already generated, memory maps etc. Each of the windows may be zoomed in, therefore providing a more detailed view of a particular feature, contents of different windows may be merged, etc. A programming editor with multiwindow facility creates a fair analogy of programmer's desk top, with all assorted documents and scratch pads being available in an electronic form at the same time.

47. Another kind of commonly used programming tools is represented by programme generators. For a variety of applications, working programmes are sufficiently stereotyped to permit their automatic generation from a suitable chosen set of design parameters. Such programme generators usually work interactively, either in a dialogue (question and answer) mode or by menu selection technique, whereby a programmer is shown a number of options, depending on the circumstances selects one, thus fixing a design decision, which triggers a next level menu to be displayed. At the end of a session, the totality of decisions made determines a particular application programme which is then produced ready for operation. Programmes produced in this way are often a bit inefficient, but otherwise quite acceptable and certainly can be used as system prototypes. If their functional behaviour is found to be satisfactory, their performance may be improved in a number of ways, e.g. by optimizing the most frequently executed parts of the code. (Incidentally, programme optimization is another task that often may be left to a suitable software tool.)

48. Finally, we should not forget that he ever growing body of commercially available compilers, interpreters, decision-table processors etc. are all in fact software tools. An extremely useful addition to this class of tools are programme transformation systems which accept a programme expressed in an abstract form and - guided by the programmer - perform textual transformations aimed at replacement of abstract algorithms by concrete ones, or at replacement of less efficient parts of code by more economic versions. The importance

of such tools rests in the fact that programme transformation systems are so designed that their action preserves the intended meaning of programmes being transformed. A programmer may therefore try a number of transformations quite safely: even if he does not achieve the intended improvement, he certainly does not run a risk of losing correctness of his programme.

49. Another class of software tools are those which gradually transform an initial design into a more and more programme-like text. Some tools of this class accept, for instance, graphic designs in form of interconnected, labelled boxes and represent them as equivalent linguistic structures more amenable to further textual refinement. (In addition to transformations between various levels of abstraction, such systems usually perform a number of useful consistency checks.) Nearly all software design methodologies advocated for general use rely on some tools of this class.

50. The most sophisticated software development tools, in addition to all previously listed facilities and standard features (such as parsers, table generators and file managers), incorporate also very advanced data bases in which programme versions and mutations are stored for easy reference and manipulation.

51. It is customary to refer to a fully developped system of software support tools as programme support environment (PSE). Modern requirements for a programming language usually include a specification for a PSE. Probabaly the best-known of them is the APSE - intended programming support environment for ADA. In fact, it is expected that the portability of ADA programme will be achieved via functional equivalent of APSE installed at nearly all computers. In this way, not only the programmes themsevels could be ported, but also their PSE, which would allow for a further development of a programme to be ported from one installation to another.

52. In addition to programme design/implementation tools, a well-developed PSE includes a variety of tools for programme testing and debugging which greatly reduce time and effort needed for the pre-release servicing of software.

Non-procedural languages and other advanced concepts in programming

53. Classic programming languages, COBOL, FORTRAN, PASCAL and even ADA, are based on the notion of assignment: as a result of the execution of a statement, a variable is assigned a new value. This notion, a direct descendant of machine order "execute and store", can be rightly described as the cornerstone of the von Neumann computer architecture.

54. New architectural concepts, such as data-flow machines, highly parallel computers and inference engines, find little use for the notion of assignment. Hence, in recent years a number of entirely different programming languages have been proposed, based on very unorthodox principles and incorporating more or less directly these architectural innovations which seem most promising from the application point of view.

55. Arguably the most widely accepted of the new line of programming languages is PROLOG, a language for programming in logic. Originally intended as a tool for computational linguistics, PROLOG is rapidly becoming the main programming language for artificial intelligence, slowly replacing in this role the old-time favourite, LISP.

56. What an assignment statement is to FORTRAN or PASCAL, a Horn clause is to PROLOG. (A Horn clause is a special form of a first order predicate calculus formula.) Its main computational advantage rests in the natural parallelism of Horn clause evaluation, while its advantage for application programming obtains from the observation that a Horn clause may be just as easily interpreted as a statement of a fact and as statement of a hypothesis to be verified based on other clauses. Close kinship of Horn clauses and relations which provide the foundations for commonly used relational data bases is another bonus for PROLOG adherents: not only does it yield an easy interface between application programmes and data bases, but also makes possible data base description by essentially same means as programme description.

57. Data flow machines seem to provide a natural evaluation mechanism for another brand of new programming languages, the so-called applicative languages, exemplified by LUCID. Hardware/software experimental systems, e.g. ALICE, are currently being built to explore new and apparently very powerful concepts of data flow and functional programming.

58. Finally, the Japanese Fifth Generation project, extremely influential in shaping the current research interests both in the USA and in Europe, favours highly parallel machine architecture harnessed to a multilevel hierarchy of specialized machines: data base machine topped with an inference engine (programmed in PROLOG) yields an expert knowledge base which, interfaced with very advanced input-output machines (such as graphic or visual computers and speech analysers and synthesisers), are to become intelligent computers of the 1990s.

59. Futuristic as such designs may seem, they do underline a new approach to computing: a merger of hardware and software design, aimed at exploitation of the potentials made available by the abundance of cheap and very efficient large chip components.

Software engineering management

60. As soon as we recognize that software writing has become the major component of the multi-billion dollar information processing industry, we must realize that this kind of industry generates its peculiar managerial problems and leads to specific managerial techniques.

61. The peculiarities of the software industry are quite pronounced. First of all, it is an industry almost totally independent of any raw materials and almost zero-energy consuming. Apart from software tools - themselves produced within software industry - it does not require much investment in material terms. Its products are often classified as intangibles, and - contrary to any other industry - most of its costs concentrate in design: the actual production (if one considers the reproduction of once composed programmes as "production") costs are practically nil. This should be contrasted not only with usual industrial sectors, such as mining or manufacturing, but also with innovation-intensive industries, such as civil engineering or drug industry. (A constructing firm may redesign a bridge ten times over, the cost of nine discarded designs is neglegible as compared with that of actually building a bridge on site. A software firm forced to redesign a major piece of software usually comes close to bankruptcy).

62. In addition, nearly all resources needed for the software industry are people: highly qualified, well educated software engineers. Hence, the managerial problems in this industry are almost exclusively pure problems of the workforce management, where the workforce in question is very independent and fully aware of its own value.

63. To fully understand the ensuing managerial difficulties, let us consider a simple example: a software team engaged to produce a system for an application, is running behind schedule. The manager decides to accelerate the rate of progress and implements this decision by hiring more programmers. Instead of expected acceleration, the work is slowed down as the fresh programmers need to be instructed about the system in production and the only available instructors are the programmers already on the job. Thus the newly hired hands are unproductive because they are not "in" yet, while the old hands, burdened with the additional task of instructing the new-comers, become less productive. Hiring even more programmers may be disastrous. After a period, the newcomers are integrated and the work may resume in earnest (although the delay has grown considerably). Now, however, the management discovers that the enlargement of the team has blown up the communication problems which grow as the square of the number of people on the project, and a sizeable portion of the total effort must be spent on overcoming the resultant communication clashes. Hiring an extra support team: secretaries, information officers and technical writers compounds the difficulty. After another couple of months the management realize that they are fighting an uphill battle: the effective rate of system production is invariant of the work expanded, it seems to be solely determined by the original design and after it has been approved there is little that the management can do to influence the rate of further development.

64. A number of managerial techniques, including the spectacularly successful "chief programmer team" approach pioneered by IBM, has been proposed and found useful. Still, the management of software projects remains a vexing problem and successful software managers are - if anything - even rarer than good programmers.